Patent Application of

Dong Lin

for

Micro-optic Polarization Beam Multiplexing/De-multiplexing System

FIELD OF THE INVENTION

The present invention relates generally to an optical multiplexing/de-multiplexing system, and in particular to a micro-optic polarization beam multiplexing/de-multiplexing system which integrates polarization beam combiner/splitter (PBC) and wavelength division multiplexer/de-multiplexer (WDM) into one optical module.

BACKGROUND OF THE INVENTION

Modern optical communication demands highly integrated and multi-functional optical components to achieve high performance in both long haul and metro optical networks. There is an increasing demand for an optical system with functions of both optical wavelength division multiplexing/de-multiplexing (WDM) and optical polarization division multiplexing/de-multiplexing (PDM). There are generally two approaches in the fiber optic passive component industry to meet this demand, the all fiber or fusion fiber approach and the micro-optic approach.

In all fiber or fusion fiber approach, a polarization beam combiner/splitter (PBC) can be fabricated by two polarization-maintaining (PM) fibers fused together. Thus, an all-fiber multiplexer/de-multiplexer can be fabricated as simple as a fiber coupler. U.S. Pat. No. 4,881,790 discloses an all-fiber system for coupling two pairs of polarized pumping sources with different wavelengths onto a single optical fiber for Raman pumping. In this system, two polarization selective couplers and one wavelength dependent type coupler are used to combine the two pairs of polarized pumping sources into two combined pumping sources with different wavelengths respectively and then multiplex the two combined pumping sources into one single pumping source.

In the micro-optic approach, an optical system with functions of both optical wavelength division multiplexing/de-multiplexing and optical polarization division multiplexing/de-multiplexing can be made as a combination of polarization beam combiners/splitters (PBC) and a wavelength division multiplexer/de-multiplexer (WDM). Optical polarization beam combiners/splitters (PBC) and wavelength division multiplexers/de-multiplexers (WDM) are known in the art. A micro-optic polarization beam combiner/splitter (PBC) can be as simple as a single piece of optical birefringent crystal, or thin film coating on a right angle prism (RAP), a Nicol prism, a Wollaston prism, a Rochon prism or a Sénarmont prism. Most of these prisms are made of biregringent material wedges serving as optical polarizers. These birefringent materials comprise Calcite, YVO_4, Rutile, $LiNbO_3$ and their equivalents. A Micro-optic

multiplexer/de-multiplexer is generally based on either of two mechanisms: angular dispersion or optic filtering. Two examples exhibiting angular dispersion are the prism and the blazed reflecting diffraction grating. Various wavelength-selective optical filters can also be used as an optical multiplexer/de-multiplexer.

U.S. Pat. No. 4,805,977 discloses an optical multiplexing system for combining and multiplexing two pairs of linear polarization beams into a single pumping source. In this system, a first polarization prism block combines the first pair of linear polarization beams having the same wavelength λ_1 into a first combined beam and a second polarization prism block combines the second pair of linear polarization beams having the same wavelength λ_2 into a second combined beam. An interference filter block is used to multiplex the first and second combined beams into a single pumping source. This prior art reference also discloses an optical multiplexing system for handling three pairs of linear polarization beams with different wavelengths by using three polarization prism blocks and two interference filter blocks. U.S. Pat. No. 6,052,394 discloses a high power pumping device which comprises a similar optical multiplexing system for multiplexing pumping radiations from four diodes by using two polarization beam combiners (PBC) and a wavelength division multiplexing combiner.

U.S. Pat. No. 5,740,288 discloses a variable polarization beam splitter, combiner and mixer. Each of the polarization beam combiner/splitter disclosed in this prior

art reference can handle one pair of polarized beams. If two or more pairs of polarized beams with different wavelengths need to be combined, two or more polarization beam combiners are still needed.

In both existing approaches, it is a common drawback that an optical system with functions of both optical wavelength division multiplexing/de-multiplexing (WDM) and optical polarization division multiplexing/de-multiplexing (PDM) is made by simply cascading the function blocks of polarization beam combiner/splitter (PBC) and wavelength division multiplexer/de-multiplexer (WDM) in series. When the number of beams or the complexity of the optical system increases, the number of optical components and the size of the optical system increase accordingly while the total performance decreases.

In view of the above, it would be an advance in the art to provide a micro-optic multiplexing/de-multiplexing which is more compact, less components, high performance and cost-effective. It would be an especially welcome advance to provide a micro-optic multiplexing/de-multiplexing system that integrates one polarization beam combiner/splitter (PBC) and one wavelength division multiplexer/de-multiplexer (WDM), e.g. an optical filter, into one optical module that can handle two or more pairs of polarization-perpendicular beams of different wavelengths.

OBJECTS AND ADVANTAGES

It is a primary object of the present invention to provide a micro-optic polarization beam multiplexing system for

multiplexing two polarization-perpendicular pairs of beams of different wavelengths into an output beam by using only one polarization beam combiner and a filter.

It is a further primary object of the present invention to provide a micro-optic polarization beam de-multiplexing system for de-multiplexing an input beam with two different wavelengths into two polarization-perpendicular pairs of beams of different wavelengths by using only one filter and one polarization beam splitter.

It is another object of the present invention to provide a micro-optic polarization beam multiplexing system for multiplexing two polarization-perpendicular pairs of beams of different wavelengths into an output beam by using one polarizing prism as the polarization beam combiner and a filter. The polarizing prism can be selected from a group consisting of Wollaston prism, Rochon prism, Sénarmont prism and their equivalents.

It is another object of the present invention to provide a micro-optic polarization beam de-multiplexing system for de-multiplexing an input beam with two different wavelengths into two polarization-perpendicular pairs of beams of different wavelengths by using only one filter and one polarizing prism as the polarization beam splitter. The polarizing prism can be selected from a group consisting of Wollaston prism, Rochon prism, Sénarmont prism and their equivalents.

It is a further object of the present invention to provide a micro-optic polarization beam multiplexing system for multiplexing two polarization-perpendicular pairs of beams of different wavelengths into an output beam by using one polarization beam combiner and a filter. The polarization beam combiner has two optical wedges and a Faraday rotator disposed between the two wedges.

It is another object of the present invention to provide a micro-optic polarization beam de-multiplexing system for de-multiplexing an input beam with two different wavelengths into two polarization-perpendicular pairs of beams of different wavelengths by using one filter and one polarization beam splitter. The polarization beam splitter has two optical wedges and a Faraday rotator disposed between the two wedges.

It is yet another object of the present invention to provide a micro-optic multiplexing system for pumping high gain Raman amplifiers and Erbium-doped fiber amplifiers (EDFA).

The micro-optic polarization beam multiplexing/de-multiplexing system of the present invention is not limited to handle two polarization-perpendicular pairs of beams of different wavelengths. By any cascading or combining techniques familiar to those skilled in the art, the micro-optic system of the present invention can be easily extended to handle three or more pairs of beams with different wavelengths.

As the micro-optic polarization beam multiplexing/de-multiplexing system of the present invention integrates the polarization beam combiner/splitter, wavelength division multiplexer/de-multiplexer (WDM), and even isolator into one optical module, it is of higher performance, less components, lower loss, lower cost and smaller footprint.

These and numerous other objects and advantages of the present invention will become apparent upon reading the detailed description.

SUMMARY

In accordance with the present invention, a micro-optic polarization beam multiplexing system for multiplexing two polarization-perpendicular pairs of beams of different wavelengths into an output beam is provided. The micro-optic system has a first collimating means for introducing a first input ordinary beam with wavelength λ_{1o} of a first pair of input beams, a second collimating means for introducing a first input extraordinary beam with wavelength λ_{1e} of the first pair of input beams, a third collimating means for introducing a second input ordinary beam with wavelength λ_{2o} of a second pair of input beams, a fourth collimating means for introducing a second input extraordinary beam with wavelength λ_{2e} of the second pair of input beams, a polarization beam combiner for combining the first pair of input beams and the second pair of input beams into a first combined light beam with wavelength λ_1 and a second combined light beam with wavelength λ_2, and a filter for multiplexing the first combined light beam and the second combined light beam into an output beam with wavelength λ_1 and wavelength

λ_2. The wavelength λ_1 equals to the wavelength λ_{1o} and the wavelength λ_{1e}, and the wavelength λ_2 equals to the wavelength λ_{2o} and the wavelength λ_{2e}. The micro-optic system also has a fifth collimating means for receiving the output beam.

The micro-optic system of the present invention further has a first subassembly holding an end of a first fiber, a second subassembly holding an end of a second fiber, a third subassembly holding an end of a third fiber, a fourth subassembly holding an end of a fourth fiber, and a fifth subassembly holding an end of a fifth fiber. Each subassembly is in paraxial relationship with the corresponding collimating means. The first fiber, the second fiber, the third fiber and the fourth fiber are polarization-maintaining optical fibers, and the fifth fiber is a single mode optical fiber. The filter can be disposed before, after or inside the polarization beam combiner.

It is apparent to those skilled in the art that this micro-optic system can be used inversely as a micro-optic de-multiplexing system for de-multiplexing an input beam with wavelength λ_1 and wavelength λ_2 into a first pair of output beams comprising a first output ordinary beam with wavelength λ_{1o} and a first output extraordinary beam with wavelength λ_{1e} and a second pair of output beams comprising a second output ordinary beam with wavelength λ_{2o} and a second output extraordinary beams with wavelength λ_{2e}.

In accordance with the present invention, there is further provided a micro-optic polarization beam multiplexing system for multiplexing two polarization-perpendicular pairs of beams of different wavelengths into an output beam by using a polarizing prism as the polarization beam combiner. The micro-optic system has a first collimating means for introducing a first input ordinary beam with wavelength λ_{1o} of a first pair of input beams, a second collimating means for introducing a first input extraordinary beam with wavelength λ_{1e} of the first pair of input beams, a third collimating means for introducing a input second ordinary beam with wavelength λ_{2o} of a second pair of input beams, and a fourth collimating means for introducing a second input extraordinary beam with wavelength λ_{2e} of the second pair of input beams.

The polarizing prism of the micro-optic polarization beam multiplexing system has a first half and a second half. The first half has a first external surface and a second external surface and the second half has a third external surface opposing to the second external surface and a fourth external surface opposing to the first external surface. The centers of the second external surface and the third external surface define an optical axis. The first half combines the first pair of input beams that are incident on the first external surface into a first combined light beam with wavelength λ_1. The second half and the first half combining the first pair of input beams that are incident on the third external surface into a second combined light beam with wavelength λ_2. A filter is disposed between the first half and the second half to

reflect light beam with wavelength λ_1 and be transparent to light beam with wavelength λ_2, thereby the filter multiplexing the first combined light beam and the second combined light beam into an output beam along the optical axis. The wavelength λ_1 equals to the wavelength λ_{1o} and the wavelength λ_{1e}, and the wavelength λ_2 equals to the wavelength λ_{2o} and the wavelength λ_{2e}. The micro-optic system also has a fifth collimating means for receiving the output beam.

The micro-optic system further has a first subassembly holding an end of a first fiber, a second subassembly holding an end of a second fiber, a third subassembly holding an end of a third fiber, a fourth subassembly holding an end of a fourth fiber, and a fifth subassembly holding an end of a fifth fiber. Each subassembly is in paraxial relationship with the corresponding collimating means. The first fiber, the second fiber, the third fiber and the fourth fiber are polarization-maintaining optical fibers, and the fifth fiber is a single mode optical fiber. The polarizing prism can be selected from a group consisting of Wollaston prism, Rochon prism, Sénarmont prism and their equivalents. A rotator can also be disposed between the two halves of the polarizing prism before or after the filter.

It is also apparent to those skilled in the art that this micro-optic system with a polarizing prism and a filter can be used inversely as a micro-optic de-multiplexing system for de-multiplexing an input beam with wavelength λ_1 and wavelength λ_2 into a first pair of output beams comprising a

first output ordinary beam with wavelength λ_{1o} and a first output extraordinary beam with wavelength λ_{1e} and a second pair of output beams comprising a second output ordinary beam with wavelength λ_{2o} and a second output extraordinary beams with wavelength λ_{2e}.

In accordance with the present invention, there is also provided a micro-optic polarization beam multiplexing system for multiplexing two polarization-perpendicular pairs of beams of different wavelengths into an output beam by using two optical wedges and a Faraday rotator as the polarization beam combiner.

The micro-optic polarization beam multiplexing system has a first collimating means for introducing a first input ordinary beam with wavelength λ_{1o} of a first pair of input beams, a second collimating means for introducing a first input extraordinary beam with wavelength λ_{1e} of the first pair of input beams, a third collimating means for introducing a second input ordinary beam with wavelength λ_{2o} of a second pair of input beams and a fourth collimating means for introducing a second input extraordinary beam with wavelength λ_{2e} of the second pair of input beams.

The polarization beam combiner has a first wedge, a second wedge, and a +45° Faraday rotator disposed between the first wedge and the second wedge. The first wedge, the faraday rotator and the second wedge are cascaded along an optical axis in a forward direction, and the second wedge is oriented 45° with respect to the first wedge in the same direction as the rotation caused by the Faraday rotator.

A filter is disposed after the second wedge. The first pair of input beams is incident in the forward direction on the first wedge symmetrically with respect to the optical axis with a predetermined convergent angle between each other. These two beams propagate through the first wedge, the Faraday rotator and the second wedge, and then are incident on the filter. The second pair of input beams is incident in a backward direction (opposite to the forward direction) on the filter symmetrically with respect to the optical axis with a predetermined convergent angle between each other.

The filter reflects the first pair of input beams with wavelength λ_1 and is transparent to the second pair of input beams with wavelength λ_2, thereby the polarization beam combiner combining the first pair of input beams into a first combined light beam with wavelength λ_1 in the backward direction along the optical axis and the second pair of input beams into a second combined light beam with wavelength λ_2 in the backward direction along the optical axis. Therefore the filter multiplexes the first combined light beam and the second combined light beam into an output beam with wavelength λ_1 and wavelength λ_2. Also, the wavelength λ_1 equals to the wavelength λ_{1o} and the wavelength λ_{1e}, the wavelength λ_2 equals to the wavelength λ_{2o} and the wavelength λ_{2e}. The micro-optic system further has a fifth collimating means for receiving the output beam. Each of the collimating means can be a separate one for one fiber or can be shared by two or all fibers at one side of the system.

The first collimating means, the second collimating means and the fifth collimating means can share a first collimator, and the third collimating means and the fourth collimating means can share a second collimator. The first collimator is positioned before the first wedge, and the second collimator is positioned after the filter.

The micro-optic system further has a first subassembly holding an end of a first fiber, a second subassembly holding an end of a second fiber, a third subassembly holding an end of a third fiber, and a fourth subassembly holding an end of a fourth fiber. The first fiber and the second fiber are polarization-maintaining fibers being positioned before the first collimator and parallel to the optical axis. The polarization directions of the first fiber and the second fiber are 90 degree apart from each other for introducing the first pair of input beams. The third fiber and the fourth fiber are polarization-maintaining fibers being positioned after the second collimator and parallel to the optical axis. The polarization directions of the third fiber and the fourth fiber are 90 degree apart from each other for introducing the second pair of input beams. The micro-optic system further has a fifth subassembly holding an end of a fifth fiber that is positioned before the first collimator and along the optical axis. The fifth fiber is a single mode optical fiber for receiving the output beam.

It is also apparent to those skilled in the art that this micro-optic system with such a design having a Faraday rotator, two optical wedges and a filter can be used

inversely as a micro-optic de-multiplexing system for de-multiplexing an input beam from the fifth fiber with wavelength λ_1 and wavelength λ_2 into a first pair of output beams comprising a first output ordinary beam with wavelength λ_{1o} and a first output extraordinary beam with wavelength λ_{1e} and a second pair of output beams comprising a second output ordinary beam with wavelength λ_{2o} and a second output extraordinary beams with wavelength λ_{2e}. Under this situation, the second wedge is oriented 45° with respect to the first wedge in the opposite direction as the rotation caused by the Faraday rotator.

The micro-optic polarization beam multiplexing system can further have a first polarizer disposed in front of the first fiber and a second polarizer disposed in front of the second fiber. The backward light beams of the first combined light beam from the fifth fiber are reflected by the filter and blocked by the first polarizer and the second polarizer respectively from entering into the first fiber and the second fiber. The backward light beams of the second combined light beam from the fifth fiber pass through the polarization beam combiner and the filter and become parallel to the optical axis, thereby being prevented from entering into the third fiber and the fourth fiber.

The micro-optic polarization beam multiplexing system of the present invention further has a six subassembly holding an end of a sixth fiber. The sixth fiber is a single mode optical fiber disposed after the second collimator along the optical axis. The light beam with telecommunication

signals propagate in the forward direction from the fifth fiber, passes through the first collimator, the polarization beam combiner, the filter and the second collimator and then enters into the sixth fiber.

The micro-optic polarization beam multiplexing system can be used to provide an output beam that is a sum or a combination of the first pair of input beams and the pair of input beams for pumping a Raman amplifier. The micro-optic system can also be used to provide an output beam that is a sum or a combination of the first pair of input beams and the second pair of input beams for pumping an EDFA.

The filter of the present invention can be a grating, a thin film, or any other tunable and non-tunable filters familiar to those skilled in the art. Each collimating means of the present invention can have a GRIN lens, or a spherical leans, an aspherical lens or any other single or array-type collimators familiar to those skilled in the art.

The micro-optic multiplexing/de-multiplexing system of the present invention is not limited to handle only two polarization-perpendicular pairs of beams of different wavelengths. By any cascading or combining techniques familiar to those skilled in the art, the Micro-optic system of the present invention can be easily extended to handle three or more pairs of beams with different wavelengths.

The above summary of the present invention is not intended to describe each disclosed embodiment or every implementation of the present invention. The figures and the detailed description will more particularly exemplify these embodiments.

BREIF DESCRIPTION OF THE FIGURES

Fig.1 is a schematic illustration of an all-fiber polarization beam multiplexing system in the prior art;

Fig.2 is a schematic illustration of a micro-optic polarization beam multiplexing system in the prior art;

Fig.3 is a schematic view of the micro-optic polarization beam multiplexing/de-multiplexing system of the present invention;

Fig.4 shows an embodiment of the micro-optic polarization beam multiplexing system of the present invention;

Fig.5 shows another embodiment of the present invention as a micro-optic polarization beam de-multiplexing system;

Fig.6 shows another embodiment of the present invention with a polarization beam combiner having two optical wedges and a Faraday rotator disposed between the two wedges;

Fig.7 illustrates the detailed optical paths of the first pair of input beams of an embodiment of the present invention;

Fig.8 illustrates the detailed optical paths of the second pair of input beams of an embodiment of the present invention;

Fig.9 shows another embodiment of the present invention as a micro-optic polarization beam de-multiplexing system;

Fig.10 shows another embodiment of the present invention as a micro-optic polarization beam multiplexing system;

Fig.11 is a schematic view of an application of the micro-optic system of Fig.10, and

Fig.12 shows yet another embodiment of the present invention as a micro-optic de-multiplexing system.

While the invention is amenable to various modifications and alternative forms, specifies thereof have been shown by way of examples in the drawings and will be described in detail. It should be understood, however, that the intention is not to limit the present invention to the particular embodiments described. On the contrary, the intention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the present invention.

DETAILED DESCRIPTION

Fig.1 is a schematic illustration of an all-fiber polarization beam multiplexing system **10** in the prior art for Raman pumping. In Fig.1, **11**, **12**, **13** and **14** refer to four individual pump sources that emit polarized radiations. Source **11** and **12** emit a first pair of polarization-perpendicular beams **30**, **31** with same wavelength λ_1. Source **13** and **14** emit a second pair of polarization-perpendicular beams **32**, **33** with same wavelength λ_2. A first polarization selective coupler **15** combines the first pair of polarization-perpendicular beams

30, 31 into a first combined beam **34** with wavelength λ_1. A second polarization selective coupler **16** combines the second pair of polarization-perpendicular beams **32, 33** into a second combined beam **35** with wavelength λ_2. A wavelength dependent type coupler **17** multiplexes the first combined beam **34** and the second combined beam **35** into an output beam **36** with wavelength λ_1 and wavelength λ_2. The fiber **21, 22, 23** and **24** are polarization-maintaining fibers and fiber **25** is a single mode optical fiber.

Fig.2 is a schematic illustration of a micro-optic polarization beam multiplexing system **10′** in the prior art for optical direct amplifier using the stimulated Raman effect. In Fig.2, a first pair of semiconductor lasers (not shown) and corresponding collimators (not shown) produce a first pair of polarization-perpendicular beams **30′, 31′** with wavelength λ_1. A second pair of semiconductor lasers (not shown) and corresponding collimators (not shown) produce a second pair of polarization-perpendicular beams **32′, 33′** with wavelength λ_2. A first polarization prism block **15′** combines the first pair of polarization-perpendicular beams **30′, 31′** into a first combined beam **34′** with wavelength λ_1. A second polarization prism block **16′** combines the second pair of polarization-perpendicular beams **32′, 33′** into a second combined beam **35′** with wavelength λ_2. An interference filter block **17′** multiplexes the first combined beam **34′** and the second combined beam **35′** into an output beam **36′** with wavelength λ_1 and wavelength λ_2.

In both Fig.1 and Fig.2, there is a common drawback of making a polarization beam multiplexing system with functions of both optical wavelength division multiplexing/de-multiplexing and optical polarization division multiplexing/de-multiplexing by simply cascading the function blocks of polarization beam combiner/splitter and wavelength division multiplexer/de-multiplexer in series. When the number of pairs of beams or the complexity of the optical system increases, the number of optical components and the size of the optical system increase accordingly while the total performance decreases.

Fig.3 is a schematic view of the micro-optic polarization beam multiplexing/de-multiplexing system **100** of the present invention. The micro-optic system **100** has a first collimating means **140** for introducing a first input ordinary beam **130** with wavelength λ_{1o} of a first pair of input beams, a second collimating means **141** for introducing a first input extraordinary beam **131** with wavelength λ_{1e} of the first pair of input beams, a third collimating means **142** for introducing a second input ordinary beam **132** with wavelength λ_{2o} of a second pair of input beams and a fourth collimating means **143** for introducing a second input extraordinary beam **133** with wavelength λ_{2e} of the second pair of input beams. A polarization beam combiner/splitter **116** combines the first pair of input beams and the second pair of input beams into a first combined light beam **134** with wavelength λ_1 and a second combined light beam **135** with wavelength λ_2. A filter **117** multiplexes the first combined light beam **134** and the second combined light beam **135** into an output beam **136** with wavelength λ_1 and wavelength λ_2. The

wavelength λ_1 equals to wavelength λ_{1o} and wavelength λ_{1e}, and the wavelength λ_2 equals to wavelength λ_{2o} and wavelength λ_{2e}. The micro-optic system further has a fifth collimating means **146** for receiving the output beam **136.**

In Fig.3, the filter **117** is disposed after the polarization beam combiner/splitter **116** for simplifying the explanation. The relationship between the filter **117** and the polarization beam combiner/splitter **116** of the present invention is not limited to this situation. The filter **117** can also be disposed before, or inside the polarization beam combiner/splitter **116.** The combining function and the multiplexing function of the micro-optic system **100** can not be absolutely considered to be independently performed by the polarization beam combiner/splitter **116** and the filter **117** respectively. These functions should be considered to be performed by the cooperation of the polarization beam combiner/splitter **116** and the filter **117** working together as an integrated module **100'**.

Each of the first input ordinary beam **130,** the first input extraordinary beam **131,** the second input ordinary beam **132** and the second input extraordinary beam **133** is defined with respect to the optic axis and material property of the first optical component of the polarization beam combiner/splitter **116** it meets. Each of the first collimating means **140,** the second collimating means **141,** the third collimating means **142,** the fourth collimating means **143** and the fifth collimating means **146** is not necessarily a separate one. Two or more of the collimating means **140, 141, 142, 143** and **146** can share one collimating

device. For example, the first collimating means **140** and the second collimating means **141** can share one collimating device. The third collimating means **142** and the fourth collimating means **143** can also share another collimating device.

As shown in Fig.3, the micro-optic system **100** of the present invention further has a first subassembly **160** holding an end of a first fiber **150** in paraxial relationship with the first collimating means **140**, a second subassembly **161** holding an end of a second fiber **151** in paraxial relationship with the second collimating means **141**, a third subassembly **162** holding an end of a third fiber **152** in paraxial relationship with the third collimating means **142**, a fourth subassembly **163** holding an end of a fourth fiber **153** in paraxial relationship with the fourth collimating means **143** and a fifth subassembly **166** holding an end of a fifth fiber **156** in paraxial relationship with the fifth collimating means **146**. In multiplexing applications, the first fiber **150**, the second fiber **151**, the third fiber **152** and the fourth fiber **153** are polarization-maintaining optical fibers, and the fifth fiber **156** is a single mode optical fiber. In the present application, the term "paraxial relationship" should be considered to cover "coaxial relationship" and "substantially coaxial relationship" and their equivalents.

Each of the first collimating means **140**, the second collimating means **141**, the third collimating means **142**, the fourth collimating means **143** and the fifth collimating means **146** has a GRIN lens, or a spherical lens, or an

aspherical lens, or any other collimating devices familiar to those skilled in the art.

The polarization beam combiner/splitter **116** can have a birefringent crystal. The optical birefringent crystal can be a material selected from group consisting of Calcite, YVO_4, Rutile and $LiNbO_3$.

The polarization beam combiner/splitter **116** can also have a prism selected from the group consisting of Glan polarizing prism, right angle prism coated with thin film, Nicol prism, Wollaston prism, Rochon prism and Sénarmont prism.

The polarization beam combiner/splitter **116** of the present invention can also comprise a first wedge, a second wedge, and a Faraday rotator disposed between the first wedge and the second wedge. The first wedge, the Faraday rotator and the second wedge are cascaded along an optical axis. The filter **117** of the present invention can be a grating, a thin film, or any other tunable and non-tunable optical filters familiar to those skilled in the art.

Still referring to Fig.3, it is apparent to those skilled in the art that the micro-optic system of Fig.3 can also be used inversely as a micro-optic polarization beam de-multiplexing system. As shown in Fig.3, the filter **117** de-multiplexes an input beam **136'** with wavelength λ_1 and wavelength λ_2 into a first de-multiplexed light beam **134'** with wavelength λ_1 and a second de-multiplexed light beam **135'** with wavelength λ_2. The polarization beam combiner/splitter **116** splits the first de-multiplexing

light beam **134′** and the second de-multiplexing light beam **135′** into a first pair of output beams comprising a first output ordinary beam **130′** with wavelength λ_{1o} and a first output extraordinary beam **131′** with wavelength λ_{1e} and a second pair of output beams comprising a second output ordinary beam **132′** with wavelength λ_{2o} and a second output extraordinary beams **133′** with wavelength λ_{2e}. The wavelength λ_1 equals to wavelength λ_{1o} and wavelength λ_{1e}, and the wavelength λ_2 equals to wavelength λ_{2o} and wavelength λ_{2e}.

Each of the first output ordinary beam **130′**, the first output extraordinary beam **131′**, the second output ordinary beam **132′** and the second output extraordinary beam **133′** is defined with respect to the optic axis and material property of the last optical component of the polarization beam combiner/splitter **116** it leaves.

The splitting function of the polarization beam combiner/splitter **116** and the de-multiplexing function of the filter **117** should not be absolutely considered to be independently performed by the polarization beam combiner/splitter **116** and the filter **117** respectively. These functions should be considered to be performed by the cooperation of the polarization beam combiner/splitter **116** and the filter **117** working together as an integrated module **100′**. However, in de-multiplexing applications, the first fiber **150**, the second fiber **151**, the third fiber **152** and the fourth fiber **153** can be polarization-maintaining optical fibers or single mode optical fibers, and the fifth fiber **156** is a single mode optical fiber.

Fig.4 shows an embodiment of the micro-optic polarization beam multiplexing system **200** of the present invention. In Fig.4, the micro-optic system **200** has a first collimating means **240** for introducing a first input ordinary beam **230** with wavelength λ_{1o} of a first pair of input beams, a second collimating means **241** for introducing a first input extraordinary beam **231** with wavelength λ_{1e} of the first pair of input beams, a third collimating means **242** for introducing a second input extraordinary beam **232** with wavelength λ_{2e} of a second pair of input beams and a fourth collimating means **243** for introducing a second input ordinary beam **233** with wavelength λ_{2o} of the second pair of input beams. The beams **230, 231, 232** and **233** are substantially collimated beams.

A polarizing prism **216** having a first half **2161** and a second half **2162** is used as the polarization beam combiner. The first half **2161** has a first external surface **1** and a second external surface **2,** and the second half **2162** has a third external surface **3** opposing to the second external surface **2** and a fourth external surface **4** opposing to the first external surface **1.** The centers of the second external surface **2** and the third external surface **3** define an optical axis **Z.** The first half **2161** combines the first pair of input beams **230, 231** which are incident on the first external surface **1** into a first combined light beam **234** with wavelength λ_1. The second half **2162** and the first half **2161** combines the second pair of input beams **232, 233** which are incident on the third external surface **3** into a second combined light beam **235** with wavelength λ_2.

A filter **217** is disposed between the first half **2161** and the second half **2162.** The filter **217** reflects light beam with wavelength λ_1 and is transparent to light beam with wavelength λ_2, thereby the filter **217** multiplexing the first combined light beam **234** and the second combined light beam **235** into an output beam **236** along the forward direction $\mathbf{A_1}$ of the optical axis **Z.** The wavelength λ_1 equals to the wavelength λ_{1o} and the wavelength λ_{1e}, and the wavelength λ_2 equals to the wavelength λ_{2o} and the wavelength λ_{2e}. The micro-optic system **200** further has a fifth collimating means **246** for receiving the output beam **236.** The point **O** is the crossing point of the optical axis **Z** and the filter **217.**

Each of the first input ordinary beam **230,** the first input extraordinary beam **231,** the second input ordinary beam **233** and the second input extraordinary beam **232** is defined with respect to the optic axis and material property of the first half **2161** or second half **2162** of the polarizing prism **216.** In Fig.4, a Sénarmont prism is used as an example of a polarizing prism **216** which is made from a uniaxial negative material, e.g. Calcite. The polarizing prism **216** can also be made from any other uniaxial negative materials and uniaxial positive materials familiar to those skilled in the art. The polarizing prism **216** can be selected from a group consisting of Wollaston prism, Rochon prism, Sénarmont prism and their equivalents.

It is apparent to those skilled in the art that the convergent angle γ between the beam **232** and beam **233,** or the

convergent angle γ between the beam **230** and beam **231** can be easily obtained. As shown in Fig.4, if the polarizing prism **216** is a Sénarmont prism with a wedge angle θ=45 degree, the angle γ can be calculated by

$$\gamma=\mathrm{arcSin}[(n_o-n_e)*\tan\theta]=\mathrm{areSin}[(n_o-n_e)] \qquad (1)$$

where n_o is the ordinary refractive index of the Sénarmont prism and n_e is the extra-ordinary refractive index of the Sénarmont prism.

Each of the first collimating means **240**, the second collimating means **241**, the third collimating means **242**, the fourth collimating means **243** and the fifth collimating means **246** is not necessarily a separate one. Two or more of the collimating means **240**, **241**, **242**, **243** and **246** can share one collimating device. For example, the first collimating means **240** and the second collimating means **241** can share one collimating device. The third collimating means **242** and the fourth collimating means **243** can share another collimating device.

As shown in Fig.4, the micro-optic system **200** of the present invention further has a first subassembly **260** holding an end of a first fiber **250** in paraxial relationship with the first collimating means **240**, a second subassembly holding **261** an end of a second fiber **251** in paraxial relationship with the second collimating means **241**, a third subassembly **262** holding an end of a third fiber **252** in paraxial relationship with the third collimating means **242**, a fourth subassembly **263** holding an end of a fourth fiber **253** in paraxial relationship with the fourth collimating means **243** and a fifth subassembly **266**

holding an end of a fifth fiber **256** in paraxial relationship with the fifth collimating means **246.** In multiplexing applications, the first fiber **250**, the second fiber **251**, the third fiber **252** and the fourth fiber **253** are polarization-maintaining optical fibers, and the fifth fiber **256** is a single mode optical fiber.

Each of the first collimating means **240**, the second collimating means **241**, the third collimating means **242**, the fourth collimating means **243** and the fifth collimating means **246** can have a GRIN lens, or a spherical lens, or an aspherical lens or any other collimating devices familiar to those skilled in the art. The filter **217** of the embodiment can be a grating, a thin film, or any other tunable and non-tunable optical filters familiar to those skilled in the art.

It is apparent to those skilled in the art that the micro-optic polarization beam multiplexing system of Fig.4 can also be used inversely as a micro-optic polarization beam de-multiplexing system.

Fig.5 shows another embodiment of the present invention as a micro-optic polarization beam de-multiplexing system **200′**. In Fig.5, the micro-optic system **200′** has a fifth collimating means **246′** for introducing the input beam **236′** with wavelength λ_1 and wavelength λ_2. A filter **217′** disposed between the first half **2161′** and second half **2162′** of the polarizing prism **216′**. The filter **217′** reflects light beam with wavelength λ_1 and is transparent to light beam with wavelength λ_2, thereby de-multiplexing the input

beam **236′** with wavelength λ_1 and wavelength λ_2 along the backward direction $\mathbf{A_2}$ of the optical axis **Z** into a first de-multiplexed light beam **234′** with wavelength λ_1 and a second de-multiplexed light beam **235′** with wavelength λ_2. Point **O′** is the crossing point of the optical axis **Z** and the filter **217′**. The first half **2161′** of the polarizing prism **216′** splits the first de-multiplexed light beam **234′** into a first pair of output beams comprising a first output ordinary beam **230′** with wavelength λ_{1o} and a first output extraordinary beam **231′** with wavelength λ_{1e}. The second half **2162′** of the polarizing prism **216′** splits the second de-multiplexed light beam **235′** into a second pair of output beams comprising a second output ordinary beam **233′** with wavelength λ_{2o} and a second output extraordinary beams **232′** with wavelength λ_{2e}.

The wavelength λ_1 equals to the wavelength λ_{1o} and the wavelength λ_{1e}, and the wavelength λ_2 equals to the wavelength λ_{2o} and the wavelength λ_{2e}. Each of the first output ordinary beam **230′**, the first output extraordinary beam **231′**, the second output ordinary beam **233′** and the second output extraordinary beam **232′** is defined with respect to the optic axis and material property of the first half **2161′** or second half **2162′** of the polarizing prism **216′**. Similarly, it is apparent to those skilled in the art that the diverging angle **γ′** between the beam **232′** and beam **233′**, or the converging angle **γ′** between the beam **230′** and beam **231′** can also be easily obtained. The polarizing prism **216′** can be selected from a group consisting of Wollaston prism, Rochon prism, Sénarmont prism and their equivalents.

The micro-optic system **200'** further has a first collimating means **240'** for receiving the first output ordinary beam **230'**, a second collimating means **241'** for receiving the first output extraordinary beam **231'**, a third collimating means **242'** for receiving the second output extraordinary beam **232'**, a fourth collimating means **243'** for receiving the second ordinary beam **233'**.

The micro-optic system **200'** can also have a first subassembly **260'** holding an end of a first fiber **250'** in paraxial relationship with the first collimating means **240'**, a second subassembly **261'** holding an end of a second fiber **251'** in paraxial relationship with the second collimating means **241'**, a third subassembly **262'** holding an end of a third fiber **252'** in paraxial relationship with the third collimating means **242'**, a fourth subassembly **263'** holding an end of a fourth fiber **253'** in paraxial relationship with the fourth collimating means **243'**, and a fifth subassembly **266'** holding an end of a fifth fiber **256'** in paraxial relationship with the fifth collimating means **246'**. In de-multiplexing applications, the first fiber **250'**, the second fiber **251'**, the third fiber **252'** and the fourth fiber **253'** can be polarization-maintaining optical fibers or single mode optical fibers, and the fifth fiber **256'** is a single mode optical fiber.

Each of the first collimating means **240'**, the second collimating means **241'**, the third collimating means **242'**, the fourth collimating means **243'** and the fifth collimating means **246'** can have a GRIN lens, or a spherical lens, or an

asperical lens, or any other collimating devices familiar to those skilled in the art. The filter **217′** of the embodiment can be a grating, a thin film, or any other tunable and non-tunable optical filters familiar to those skilled in the art.

Fig.6 shows another embodiment of the present invention with a polarization beam combiner having two optical wedges and a Faraday rotator disposed between the two wedges. In Fig.6, the micro-optic polarization beam multiplexing system **300** has a first collimating means **340** for introducing a first input ordinary beam **330** with wavelength λ_{1o} of a first pair of input beams, a second collimating means **341** for introducing a first input extraordinary beam **331** with wavelength λ_{1e} of the first pair of input beams, a third collimating means **342** for introducing a second input ordinary beam **332** with wavelength λ_{2o} of a second pair of input beams, a fourth collimating means **343** for introducing a second input extraordinary beam **333** with wavelength λ_{2e} of the second pair of input beams.

The polarization beam combiner **316** has a first wedge **3161**, a second wedge **3162** and a +45° Faraday rotator **3163** disposed between the first wedge **3161** and the second wedge **3162**. The first wedge **3161**, the Faraday rotator **3163** and the second wedge **3162** are cascaded along an optical axis **Z** in a forward direction $\mathbf{A_1}$. The second wedge **3162** is oriented 45° with respect to the first wedge **3161** in the same direction as the rotation caused by the Faraday rotator **3163**.

The polarization directions of the first input ordinary beam **330** and the first input extraordinary beam **331** are 90 degrees apart from each other, such that the first input ordinary beam **330** is an ordinary ray to the first wedge **3161** and the first input extraordinary beam **331** is an extraordinary ray to the first wedge **3161**. The polarization directions of the second input ordinary beam **332** and the second input extraordinary beam **333** are 90 degrees apart from each other, such that the second input ordinary beam **332** is an ordinary ray to the second wedge **3162** and the second input extraordinary beam **333** is an extraordinary ray to the second wedge **3162**.

A filter **317** is disposed after the second wedge **3162**. The first pair of input beams **330, 331** are incident in the forward direction $\mathbf{A_1}$ on the first wedge **3161** symmetrically with respect to optical axis **Z** with a predetermined convergent angle β (see also Fig.7) between each other, propagate through the first wedge **3161**, the Faraday rotator **3163** and the second wedge **3162**, and then incident on the filter **317**. The second pair of input beams **332, 333** are incident in a backward direction $\mathbf{A_2}$ opposite to the forward direction $\mathbf{A_1}$ on the filter **317** symmetrically with respect to the optical axis **Z** with a predetermined convergent angle β (see also Fig.8) between each other.

The filter **317** reflects the first pair of input beams **330, 331** with wavelength λ_{1o} and wavelength λ_{1e} and is transparent to the second pair of input beams **332, 333** with wavelength λ_{2o} and wavelength λ_{2e}. Thus, the polarization beam combiner **316** combines the first pair of input beams **330, 331** into a

first combined light beam **334** with wavelength λ_1 in the backward direction $\mathbf{A_2}$ along the optical axis **Z** and the second pair of input beams **332, 333** into a second combined light beam **335** with wavelength λ_2 in the backward direction $\mathbf{A_2}$ along the optical axis **Z.** At the same time, the filter **317** multiplexes the first combined light beam **334** and the second combined light beam **335** into an output beam **336.** The wavelength λ_1 equals to the wavelength λ_{1o} and the wavelength λ_{1e}, and the wavelength λ_2 equals to the wavelength λ_{2o} and the wavelength λ_{2e}. The micro-optic system further has a fifth collimating means **346** for receiving the output beam **336.**

As shown in Fig.6, the micro-optic system **300** of the present invention further has a first subassembly **360** holding an end of a first fiber **350** in paraxial relationship with the first collimating means **340,** a second subassembly holding **361** an end of a second fiber **351** in paraxial relationship with the second collimating means **341,** a third subassembly **362** holding an end of a third fiber **352** in paraxial relationship with the third collimating means **342,** a fourth subassembly **363** holding an end of a fourth fiber **353** in paraxial relationship with the fourth collimating means **343** and a fifth subassembly **366** holding an end of a fifth fiber **356** in paraxial relationship with the fifth collimating means **346.** The first fiber **350,** the second fiber **351,** the third fiber **352** and the fourth fiber **353** are polarization-maintaining optical fibers, and the fifth fiber **356** is a single mode optical fiber.

Each of the first collimating means **340**, the second collimating means **341**, the third collimating means **342**, the fourth collimating means **343** and the fifth collimating means **346** can have a GRIN lens, or a spherical lens, or an asperical lens, or any other collimating devices familiar to those skilled in the art. The filter **317** of the embodiment can be a grating, a thin film, or any other tunable and non-tunable optical filters familiar to those skilled in the art.

Fig.7 illustrates the detailed optical paths of the first pair of input beams **330, 331** of the embodiment. In Fig.7, the polarization directions of the first input ordinary beam **330** and the first input extraordinary beam **331** are 90 degrees apart from each other, such that the first input ordinary beam **330** is an ordinary ray to the first wedge **3161** and the first input extraordinary beam **331** is an extraordinary ray to the first wedge **3161**. After passing through the first wedge **3161** in a forward direction $\mathbf{A_1}$, beam **330** and beam **331** are rotated 45 degree by the Faraday rotator **3163**. Since the optic axis of the second wedge **3162** is oriented 45 degree with respect to the optic axis of the first wedge **3161** and in the same direction as the rotation caused by the Faraday rotator **3163**. So the beam **331** is still the extraordinary ray to the second wedge **3162** and the beam **330** is still the ordinary ray to the second wedge **3162**. Beam **330** and beam **331** travel in the same direction in the second wedge **3162** as they do in the first wedge **3161**.

After reflected by the filter **317**, the beam **330** and beam **331** travel through the second wedge **3162**, the Faraday rotator **3163** and the first wedge **3161** in a backward direction $\mathbf{A_2}$ as shown in Fig.7. Since the optic axis of the first wedge **3161** is oriented 45 degree with respect to the optic axis of the second wedge **3162** and in the opposite direction as the rotation caused by the Faraday rotator **3163**, the beam **331** which is an extraordinary ray of the second wedge **3162** becomes an ordinary ray of the first wedge **3161** while the beam **330** which is an ordinary ray of the second wedge **3162** becomes extraordinary ray of the first wedge **3161**. So the beam **330** and beam **331** are combined in the backward direction $\mathbf{A_2}$ into the first combined beam **334**.

In Fig.7, small letters **o** and **e** indicate the extraordinary and ordinary statuses of the beam **330** and beam **331** at different locations. The first pair of input beams **330**, **331** and the first combined beam **334** are substantially collimated beams.

Fig.8 illustrates the detailed optical paths of the second pair of input beams **332**, **333** of the embodiment. In Fig.8, the polarization directions of the second input ordinary beam **332** and the first input extraordinary beam **333** are 90 degrees apart from each other, such that the second input ordinary beam **332** is an ordinary ray to the second wedge **3162** and the second input extraordinary beam **333** is an extraordinary ray to the second wedge **3162**.

After passing through the filter **317**, the beam **332** and beam **333** travel through the second wedge **3162**, the Faraday rotator **3163** and the first wedge **3161** from right to left along a backward direction $\mathbf{A_2}$ as shown in Fig.8. Since the optic axis of the first wedge **3161** is oriented 45 degree with respect to the optic axis of the second wedge **3162** and in the opposite direction as the rotation caused by the Faraday rotator **3163**, the beam **333** which is an extraordinary ray of the second wedge **3162** becomes an ordinary ray of the first wedge **3161** while the beam **332** which is an ordinary ray of the second wedge **3162** becomes extraordinary ray of the first wedge **3161**. So the beam **332** and beam **333** are combined in the backward direction $\mathbf{A_2}$ into the second combined beam **335**.

In Fig.8, small letters **o** and **e** indicate the extraordinary and ordinary statuses of the beam **332** and beam **333** at different locations. The second pair of input beams **332**, **333** and the first combined beam **335** are substantially collimated beams.

It is also apparent to those skilled in the art that the convergent angle β between the beam **331** and beam **330** in Fig.7, or the convergent angle β between the beam **332** and beam **333** in Fig.8 can be easily obtained. As shown in Figs.7 and 8, the angle β can be calculated by

$$\beta=2*\arcsin[(n_o-n_e)*\tan\alpha] \qquad (2)$$

where α is the incline angle of the second surface **3161b** of the first wedge **3161** and the incline angle of the first surface **3162a** of the second wedge **3162**, n_o is the ordinary refractive index of the two wedges and n_e is the extra-

ordinary refractive index of the two wedges. The optic axis of the first wedge **3161** is oriented 45 degree with respect to the optic axis of the second wedge **3162**. Both he optic axis of the first wedge **3161** and the optic axis of the second wedge **3162** are parallel to the first surface **3161a** of the first wedge **3161** and the second surface **3162b** of the second wedge **3162**.

Similarly, the micro-optic system of the embodiment of Fig.6 can also be use inversely as a micro-optic polarization beam de-multiplexing system. Fig.9 shows such a micro-optic polarization beam de-multiplexing system as another embodiment of the present invention. In Fig.9, the micro-optic system **300'** has a fifth collimating means **346'** for introducing an input beam **336'** with wavelength λ_1 and wavelength λ_2, a polarization beam splitter **316'** having a first wedge **3161'**, a second wedge **3162'**, and a +45° Faraday rotator **3163'** disposed between the first wedge **3161'** and the second wedge **3162'**. The first wedge **3161'**, the Faraday rotator **3163'** and the second wedge **3161'** are cascaded along an optical axis **Z** in a forward direction $\mathbf{A_1}$. The second wedge **3162'** is oriented 45° with respect to the first wedge **3161'** in the opposite direction as the rotation caused by the Faraday rotator **3163'**.

A filter **317'** is disposed after the second wedge **3162'**. The input beam **336'** is incident along the optical axis **Z** in the forward direction $\mathbf{A_1}$, passes through the polarization beam splitter **316'** and then incident on the filter **317'**. The filter **317'** reflects the portion of light beams with wavelength λ_1 of the input beam **336'** and is transparent to

the portion of light beams with wavelength λ_2 of the input beam **336'**, thereby the filter **317'** de-multiplexing the input beam **336'** into a first de-multiplexed light beam **334'** with wavelength λ_1 and a second de-multiplexed light beam **335'** with wavelength λ_2. The polarization beam splitter **316'** splits the first de-multiplexed light beam **334'** into a first pair of output beams comprising a first output ordinary beam **330'** with wavelength λ_{1o} and a first output extraordinary beam **331'** with wavelength λ_{1e} in a backward direction $\mathbf{A_2}$ symmetrically with respect to the optical axis **Z** with a predetermined diverging angle β' between each other, and the second de-multiplexed light beam **335'** into a second pair of output beams comprising a second output ordinary beam **332'** with wavelength λ_{2o} and a second output extraordinary beams **333'** with wavelength λ_{2e} in the forward direction $\mathbf{A_1}$ symmetrically with respect to the optical axis **Z** with a predetermined diverging angle β' between each other. The wavelength λ_1 equals to wavelength λ_{1o} and wavelength λ_{1e}, and the wavelength λ_2 equals to wavelength λ_{2o} and wavelength λ_{2e}. In Fig.9, it is clear to those skilled in the art that the splitting function of the polarization beam splitter **316'** starts before the input beam **336'** reaches the filter **317'**.

Similarly, it is also apparent to those skilled in the art that the convergent angle β' between the beam **331'** and beam **330'** and the convergent angle β' between the beam **332'** and beam **33** in Fig.9 can be easily obtained (see also equation (2) and Figs.7 and 8).

The micro-optic system further has a first collimating means **341′** for receiving the first output ordinary beam **330′**, a second collimating means **341′** for receiving the first output extraordinary beam **331′**, a third collimating means **342′** for receiving the second output ordinary beam **332′** and a fourth collimating means **343′** for receiving the second output extraordinary beam **333′**.

As shown in Fig.9, the micro-optic system **300′** of the present invention further has a first subassembly **360′** holding an end of a first fiber **350′** in paraxial relationship with the first collimating means **340′**, a second subassembly holding **361′** an end of a second fiber **351′** in paraxial relationship with the second collimating means **341′**, a third subassembly **362′** holding an end of a third fiber **352′** in paraxial relationship with the third collimating means **342′**, a fourth subassembly **363′** holding an end of a fourth fiber **353′** in paraxial relationship with the fourth collimating means **343′** and a fifth subassembly **366′** holding an end of a fifth fiber **356′** in paraxial relationship with the fifth collimating means **346′**. In de-multiplexing applications, the first fiber **350′**, the second fiber **351′**, the third fiber **352′** and the fourth fiber **353′** can be polarization-maintaining optical fibers or single mode optical fibers, and the fifth fiber **356′** is a single mode optical fiber.

Each of the first collimating means **340′**, the second collimating means **341′**, the third collimating means **342′**, the fourth collimating means **343′** and the fifth collimating means **346′** can have a GRIN lens, or a spherical lens, or an

aspherical lens or any other collimating devices familiar to those skilled in the art. The filter **317'** of the embodiment can be a grating, a thin film, or any other tunable and non-tunable optical filters familiar to those skilled in the art.

Fig.10 shows another embodiment of the present invention as a micro-optic polarization beam multiplexing system. In Fig.10, the micro-optic system **400** has a first subassembly **460** holding an end of a first fiber **450**, a second subassembly **461** holding an end of a second fiber **451**. The first fiber **450** and the second fiber **451** are polarization-maintaining fibers being positioned before the first collimator **471** and parallel to the optical axis **Z**. The tips of the first fiber **450** and the second fiber **451** are one focus (of the first collimator **471**) away from the first collimator **471**. The polarization directions of the first fiber **450** and the second fiber **451** are 90 degree apart from each other for introducing the first pair of input beams **430** and **431**.

The micro-optic system **400** also has a third subassembly **462** holding an end of a third fiber **452** and a fourth subassembly **463** holding an end of a fourth fiber **453**. The third fiber **452** and the fourth fiber **453** are polarization-maintaining fibers being positioned after the second collimator **472** and parallel to the optical axis **Z**. The tips of the third fiber **452** and the fourth fiber **453** are one focus (of the second collimator **472**) away from the second collimator **472**. The polarization directions of the third fiber **452** and the fourth fiber **453** are 90 degree

apart from each other for introducing the second pair of input beams **432** and **433.**

A fifth subassembly **466** holding an end of a fifth fiber **456** is being positioned before the first collimator **471** and along the optical axis **Z.** The tip of the fifth fiber **456** is also one focus (of the first collimator **471**) away from the first collimator **471.** The fifth fiber is a single mode optical fiber for receiving the output beam **436.** Each of the first collimator **471 and** the second collimator **472** can have a GRIN lens, or a spherical lens, or an aspherical lens or any other collimating devices familiar to those skilled in the art.

The polarization beam combiner **416** has a first wedge **4161,** a second wedge **4162** and a +45° Faraday rotator **4163** disposed between the first wedge **4161** and the second wedge **4162.** The first wedge **4161,** the Faraday rotator **4163** and the second wedge **4162** are cascaded along the optical axis **Z** in a forward direction $\mathbf{A_1}$. The second wedge **4162** is oriented 45° with respect to the first wedge **4161** in the same direction as the rotation caused by the Faraday rotator **4163.** A filter **417** is disposed after the second wedge **4162.**

The working principles of the polarization beam combiner **416** and the filter **417** of this embodiment as shown in Fig.10 are similar to the corresponding working principles of the embodiment of Figs.6 to 8. The filter **417** reflects the first pair of input beams **430, 431** with wavelength λ_{1o} and wavelength λ_{1e} and is transparent to the second pair of

input beams **432, 433** with wavelength λ_{2o} and wavelength λ_{2e}. Thus, the polarization beam combiner **416** combines the first pair of input beams **430, 431** into a first combined light beam **434** with wavelength λ_1 in the backward direction $\mathbf{A_2}$ along the optical axis **Z** and the second pair of input beams **432, 433** into a second combined light beam **435** with wavelength λ_2 in the backward direction $\mathbf{A_2}$ along the optical axis **Z.** At the same time, the filter **417** multiplexes the first combined light beam **434** and the second combined light beam **435** into an output beam **436.**

Still referring to Fig.10, the micro-optic system **400** further has a first polarizer **481** and a second polarizer **482.** The first polarizer **481** is disposed in front of the first fiber **450** and the polarization direction of the first polarizer **481** is same as that of the first fiber **450.** The a second polarizer **482** is disposed in front of the second fiber **451** and the polarization direction of the second polarizer **482** is same as that of the second fiber **451.** The backing light beams $\mathbf{B_1}$ of the first pair of input beams **430, 431** from the fifth fiber **456** are reflected by the filter **417** and blocked by the first polarizer **481** and the second polarizer **482** respectively from entering into the first fiber **450** and the second fiber **451.** The backing light beams $\mathbf{B_2}$ of the second pair of input beams **432, 433** from the fifth fiber **456** pass through the polarization beam combiner **416** and the filter **417** and become parallel to the optical axis **Z,** thereby being prevented from entering into the third fiber **452** and the fourth fiber **453.** Each of the first polarizer **481** and the second polarizer **482** can have

any form of polarizers familiar to those skilled in the art, e.g. a sheet polarizer.

The micro-optic system **400** of the present invention further has a six subassembly **467** holding an end of a sixth fiber **457**. The sixth fiber **457** is a single mode optical fiber disposed after the second collimator **472** along the optical axis **Z** and the tip of the sixth fiber **457** is one focus (of the second collimator **472**) away from the second collimator **472**. The light beam ($\mathbf{T_1}$) with telecommunication signals propagating in forward direction $\mathbf{A_1}$ from the fifth fiber **456** passes through the first collimator **471**, the polarization beam combiner **416**, the filter **417** and the second collimator **472** and then becomes $\mathbf{T_2}$ entering into the sixth fiber **457**.

The micro-optic polarization beam multiplexing system of the embodiment can be used for Raman pumping. Fig.11 is a schematic view of an application of the micro-optic system of Fig.10. In Fig.11, System **500** is the micro-optic polarization beam multiplexing system of Fig.10. The polarization-maintaining fibers **550** and **551** introduce a first pair of input radiations from the first pair of sources $\mathbf{S_1}$ and $\mathbf{S_2}$. The polarization-maintaining fibers **552** and **553** introduce a second pair of input radiations from the second pair of sources $\mathbf{S_3}$ and $\mathbf{S_4}$. The output radiation **536** of the system **500** is the combination of the first pair of input radiations and the second pair of input radiations for Raman pumping. The telecommunication signals ($\mathbf{T_1}$, signal in) propagating in forward direction $\mathbf{A_1}$ from the single mode optical fiber **556** passes through the system **500** and then enters into the single mode optical fiber **557** ($\mathbf{T_2}$,

signal out). In one example of the application, the wavelengths λ_{1o}, λ_{1e} of the first pair of input radiations **550, 551** are substantially 1435 nm and the wavelengths λ_{2o} and λ_{2e} of the second pair of input radiations **552, 553** are substantially 1455 nm.

Due to the unique design of the micro-optical polarization beam multiplexing system of the embodiment of Fig.10, only one polarization beam combiner and one filter are used. Also, no isolator is needed due to the introduction of the first polarizer **481**, second polarizer **482** and the unique structure of the system **400** as shown in Fig.10. It is apparent to those skilled in the art that the micro-optic polarization system **400** of the embodiment as shown in Fig.10 can also be used for pumping an EFDA.

Fig.12 shows yet another embodiment of the present invention as a micro-optic de-multiplexing system. In Fig.12, the micro-optic polarization beam de-multiplexing system **400′** has a first subassembly **460′** holding an end of a first fiber **450′**, a second subassembly **461′** holding an end of a second fiber **451′**. The first fiber **450′** and the second fiber **451′** are polarization-maintaining fibers or single mode optical fibers being positioned before the first collimator **471′** and parallel to the optical axis **Z**. The tips of the first fiber **450′** and the second fiber **451′** are one focus (of the first collimator **471′**) away from the first collimator **471′**.

The micro-optic system **400′** also has a third subassembly **462′** holding an end of a third fiber **452′** and a fourth

subassembly **463′** holding an end of a fourth fiber **453′**. The third fiber **452′** and the fourth fiber **453′** are polarization-maintaining fibers or single mode optical fibers being positioned after the second collimator **472′** and parallel to the optical axis **Z**. The tips of the third fiber **452′** and the fourth fiber **453′** are one focus (of the second collimator **472′**) away from the second collimator **472′**.

A fifth subassembly **466′** holding an end of a fifth fiber **456′** is positioned before the first collimator **471′** and along the optical axis **Z**. The tip of the fifth fiber **456′** is also one focus (of the first collimator **471′**) away from the first collimator **471′**. The fifth fiber **456′** is a single mode optical fiber for introducing the input beam **436′**.

The polarization beam splitter **416′** has a first wedge **4161′**, a second wedge **4162′** and a +45° Faraday rotator **4162′** disposed between the first wedge **4161′** and the second wedge **4162′**. The first wedge **4161′**, the Faraday rotator **4163′** and the second wedge **4162′** are cascaded along an optical axis **Z** in a forward direction $\mathbf{A_1}$. The second wedge **4162′** is oriented 45° with respect to the first wedge **4161′** in the opposite direction as the rotation caused by the Faraday rotator **4163′**. A filter **417′** is disposed after the second wedge **4162′**.

The working principles of the polarization beam splitter **416′** and the filter **417′** of this embodiment as shown in Fig.12 are similar to the corresponding working principles

of the embodiment of Fig.9. The filter **417′** reflects the portion of light beams with wavelength λ_1 of the input beam **436′** and is transparent to the portion of light beams with wavelength λ_2 of the input beam **436′**, thereby the filter **317′** de-multiplexing the input beam **436′** into a first de-multiplexed light beam **434′** with wavelength λ_1 and a second de-multiplexed light beam **435′** with wavelength λ_2. The polarization beam splitter **416′** splits the first de-multiplexed light beam **434′** into a first pair of output beams comprising a first output ordinary beam **430′** with wavelength λ_{1o} and a first output extraordinary beam **431′** with wavelength λ_{1e}, and the second de-multiplexed light beam **435′** into a second pair of output beams comprising a second output ordinary beam **432′** with wavelength λ_{2o} and a second output extraordinary beams **433′** with wavelength λ_{2e}.

Each subassembly for holding a fiber in the present invention can be any form of single or array-type subassembly familiar to those skilled in the art. Also, each subassembly is not necessarily a separate one. Two or more subassemblies can share one fiber-holding and adjusting device familiar to those skilled in the art.

The embodiments of the present invention should not be considered to handle only two pairs of polarization-perpendicular beams. By methods of duplicating, cascading or combining familiar to those skilled in the art, the embodiments of the present invention can be used to handle more than two pairs of polarization-perpendicular beams. Different embodiments of the present invention can also

work together to handle more pairs of polarization-perpendicular beams with different wavelengths.

The present invention should not be considered limited to the particular examples described above, but rather should be understood to cover all aspects of the present invention as fairly set out in the attached claims. Various modifications, equivalents, as well as numerous geometrical configurations to which the present invention may be applicable will be readily apparent to those of skill in the art to which the present invention is directed upon review of the present specification.